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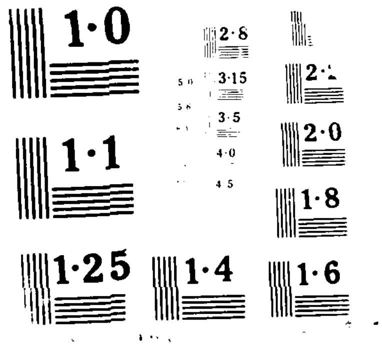
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Research Opportunities Below 300 nm at the NBS Free-Electron Laser Facility*

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Average output power of 25 W in 3 ps pulses at 75 MHz will be available at fundamental wavelengths from 200 to 300 nm beginning in April, 1990.

[To be presented at the OSA topical meeting on Free-Electron Laser Applications in the Ultraviolet.]

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A free-electron laser (FEL) user facility is being constructed at the Center for Radiation Research of the National Bureau of Standards in collaboration with the Plasma Physics Division of the Naval Research Laboratory. The FEL, which will be driven by the NBS-LANL cw racetrack microtron (RTM), will be operated as an oscillator with the fundamental wavelength variable from approximately 200 nm to 10 μm. The presence of harmonics should allow for operation in the VUV and EUV spectral regions. The FEL will be operational by April, 1990.

The NBS-LANL cw RTM consists of a 5 MeV injector section and a 12 MeV, cw, rf linear accelerator (linac).[1] The linac is placed between two uniform-field end magnets that recirculate the beam on successive orbits through the linac. The beam can be deflected out of the RTM after completing up to and including 15 passes through the linac, so that the final beam energy is 17 MeV to 185 MeV. As a FEL driver, the unique features of the RTM are the cw nature of the beam, excellent energy stability, small values of the transverse emittance and energy spread, and high average power.

A series of detailed measurements has been completed on the 5 MeV injector.[2] The injector produces a beam of 3-ps wide pulses at 2380 MHz at an average current of up to [illegible] μA. Averaged over several values of beam energy and current, the measured, normalized, transverse beam emittance is ϵ_n = 0.6 μm. The measured longitudinal emittance is approximately 5 keV-degrees. These

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values represent 95% of the total beam current. The measured full-width energy spread is 5 keV at 5 MeV.

The RTM injector will be modified before the machine is used as a FEL driver. The average beam current is constrained by power considerations to be about 600 μA, which, at 2380 MHz, gives values of the peak current that are too low to have reasonable gain in the FEL. We will decrease the repetition rate of the electron beam to a sub-multiple of the RTM frequency to allow peak currents in the range of 2 A to 4 A. To achieve this, we plan to replace the present thermionic electron gun with a laser-driven photocathode gun. Experiments at Los Alamos have demonstrated that a high-brightness, high-frequency electron source can be made by illuminating a Cs_3Sb photocathode with the 532 nm radiation from a cw, mode-locked Nd:YAG laser.[3] In our case, the laser will be mode-locked at 74.375 MHz and synchronized with the RTM frequency. The design goal for the pulse width at 5 MeV is 3 ps.

Our wiggler specifications call for a linearly polarized magnetic field with a peak amplitude of 5400 Gauss, a minimum gap spacing of 1.0 cm, and a period of 2.8 cm. A wiggler with 130 periods will be used for the UV and visible spectral regions. In the IR, diffraction losses limit the wiggler length to 65 periods.

Our collaborators at NRL have calculated the small-signal fractional power gain in the one-dimensional, low gain, single-particle limit. They also repeated the calculation with a three-dimensional numerical method that includes the transverse beam emittance.[4] These calculations indicate that lasing should be possible from about 200 nm to 10 μm, with small signal power gains between 6% and 35%. In the fundamental, the small value of the gain in the UV determines the 200 nm cutoff. We expect to have adequate gain in the third harmonic for operation as an oscillator down to about 150 nm.

The optical resonator of the FEL is designed to produce a waist at the center of the wiggler, thus maximizing the interaction of the electromagnetic radiation and the electron beam. In addition, the length between the two spherical cavity mirrors is adjusted so that the inverse of the round trip light travel time is a sub-multiple of 2380 MHz. We have chosen the mirror separation to be 8.062 m. Therefore, the NBS FEL will resemble a high power, picosecond, tunable, cw, mode-locked laser with four light pulses in the cavity simultaneously, at a repetition rate of 74.375 MHz. As a later project, we will provide other repetition rates. We will change the wavelength by exploiting the relationship between the energy of the electron beam and the wavelength. We will scan the wavelength by changing the gap spacing between the wiggler poles. Scans of ± 20% appear feasible, depending on the spectral bandwidth of the cavity mirrors.

The fractional power gain per pass for a saturated FEL in the low-gain regime for an ideal, untapered wiggler having N periods is $\eta \langle P \rangle_b / P_{cav}$, where $\eta = 1/2N$ and $\langle P \rangle_b$ is the average power in the electron beam. The electron beam power depends on the beam kinetic energy, the repetition rate, the peak current, and the pulse width. The kinetic energy can be expressed in terms of the optical wavelength through the FEL resonance condition, so that for typical cavity losses, the average intracavity and output optical power can be expressed as a function of wavelength (see Table 1). The output will be linearly polarized, the spatial mode will be TEM_{00}, and the spectral bandwidth will be Fourier-transform limited by the temporal pulse width. The reflectivity of the high reflector mirror, R_{HR}, and the transmission of the output coupler, T, are

also given in the table, along with the radius of the TEM_{00} mode at the waist and the divergence half-angle.

Table 1

UV Output of the NBS FEL at 74.375 MHz, with 3 ps-wide pulses, 2 \ peak current, and B_o = 5400 Gauss.

λ nm	R_{HR}	T	<P> W	P kW	E μJ	I $MW\text{-}cm^{-2}$	σ_o mm	$\Theta_{1/2}$ mrad
200	0.975	0.005	29	130	0.39	77	0.23	0.27
250	0.980	0.005	32	140	0.42	66	0.26	0.30
300	0.985	0.010	67	300	0.90	110	0.29	0.32

There will be two experimental rooms in the user facility. The first, which comprises about 1600 ft^2, is on a direct line of sight with the FEL, so that UV radiation can be delivered to the users with a minimum of reflection losses. This room is located underground and is shielded from the FEL by a 12-ft thick concrete wall. The second room, which comprises 2000 ft^2, will be an addition at ground level. Inquiries and/or input from potential users are welcome; comments should be addressed to Chief, Radiation Source and Instrumentation Division, Building 245, National Bureau of Standards, Gaithersburg, MD 20899, USA.

References

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2. M.A. Wilson et al., "Performance of the 5 MeV Injector for the NBS-Los Alamos Racetrack Microtron", to appear in the 1987 PAC proceedings.

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4. C.-M. Tang et al., "Analysis of Free Electron Laser Performance Utilizing the National Bureau of Standards' CW Microtron", to appear in the 1987 PAC Proceedings.

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